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WIND DRIFT AND SURFACE CURRENTS IN THE OCEANS

by

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One method by which we can get to know something about ocean surface currents is that of keeping track of a drifting object such as a bottle, a plastic card, an ice-berg or a drifting derelict ship. Many glass balls, used by Japanese fishermen as floats for their nets, and debris from wrecked Chinese junks have been found along the west coast of North America, from which it can be inferred that a surface current runs from west to east right across the Pacific Ocean.

From accidental discoveries like this only qualitative conclusions can be reached; there are too many uncertain factors to permit any quantitative deductions. The time when the object began its journey may not be known, or how long it had been lying on the beach before being found; it may not have travelled directly from the point of launching to the point of discovery, but instead taken a roundabout route, which one does not know; lastly, if the object projects quite appreciably above the water, its route may have been determined just as much by the wind as by the current.

The length of time an object might remain undiscovered is illustrated by the following incident. In 1856 the brig *Griften* was badly damaged in a storm in the Bay of Biscay and in order to carry out the necessary repairs, she was anchored off a small cape opposite Gibralta. When the captain returned from a hunting trip ashore he found the sea had risen and it was necessary to ballast the lifeboat with some large rocks found on the beach. One of these "rocks" turned out to be a small keg barnacled beyond recognition. Inside the keg the seamen found a tarred coconut and in the nut a message, written in Gothic characters on old parchment, from Christopher Columbus to the King and Queen of Spain. This message, which reported the loss of the *Santa Maria* and the mutiny on the *Nina*, had drifted at sea and lain on shore for 358 years.

Observations of drifting pieces of volcanic pumice have been used to calculate the average speed as well as the direction of certain ocean currents. In 1952 Barceno Volcano erupted on San Benedetto Island in the Pacific Ocean off the coast of Central America. Some of the pumice emitted was picked up in Hawaii 264 days later and some more on Wake Island 562 days later. The speed of the North Equatorial Current of the Pacific Ocean, calculated from these figures, averaged 9.8 miles a day.

Probably the longest drift on record was that of a bottle released on June 20th 1962, at Perth, Australia and recovered almost 5 years later near Miami, Florida. It has been estimated that the bottle had travelled some 16,000 miles at an average speed of about ten miles per day. The route is unknown, but it was most probably around the Cape of Good Hope, north along the west coast of Africa, across the Atlantic to northern Brazil, north along the South American coast into the Gulf of Mexico, and through the Florida Straits to Miami.

Wind and surface current may have different effects on a drifting object. This can be seen from the following instance. On 22nd June, 1892, the schooner *Fred Taylor* broke in two in a collision with the *S.S. Trave*, off Nantucket Island on the east coast of the U.S.A. Both sections continued to drift for about six months but in opposite directions; the bow drifted northwards and eventually went aground on the Maine Coast, north of Boston, while the stern drifted south-westward and finally sank in the mouth of Delaware Bay. Altogether, the two sections drifted some 500 miles apart. What had happened was that the forepart of the ship projected well above the surface of the ocean and was driven northward by the prevailing south-westerly winds, while the stern, which had settled deep into the water was carried along by the surface current which was running towards the south-west.

THE EKMAN SPIRAL

The fact that the direction of surface drift in the oceans is not necessarily the same as the direction of prevailing winds was investigated

theoretically around the turn of this century. About 1900 Nansen was evaluating the results of his investigations into the movements of polar ice, in which he had drifted in the ice-bound *Fram* through the Arctic Ocean during the years 1893-96. He noticed that when the wind had blown in a certain direction for a long time, the icebergs did not follow the wind direction but drifted some 20-40 degrees to the right. He came to the conclusion that the action of the earth's rotation, known as the Coriolis force, was responsible for the surface layer of the ocean being deflected to the right of the wind direction, and the ice-bergs, which have 90 percent of their bulk below the water surface, moved in the direction of this surface current. He reasoned further that deeper layers of water probably deviated to the right even more than the upper layer, because, just as the upper layer is deflected by the earth's rotation to the right relative to the wind direction, so are the deeper layers of water deflected towards the right relative to the upper layers, and therefore deviate from the wind at an even greater angle than the upper layers.

At Nansen's suggestion a young physicist, Ekman, studied the problem mathematically in 1902. The outcome was a theory of wind-drift currents taking account of the earth's rotation. He assumed infinitely deep water for the lower boundary condition with an x-axis perpendicular to a y-axis and pointing to the right of it, both in the surface of the ocean, while the z-axis pointed downward. With the wind stress τ acting in the direction of the positive x-axis he arrived at the following formulae for current speeds u, v in the x and y directions, at latitude ϕ,

$$u = V_w \, e^{-\lambda^2} \cos(45^\circ - \lambda z)$$

$$v = V_w \, e^{-\lambda^2} \sin(45^\circ - \lambda z)$$

where

$$\lambda = \pi/D \,, \qquad D = \sqrt{A/\rho\omega \sin\phi}$$

$$V_w = \tau/Aa, \qquad a = \sqrt{2\rho\omega \sin\phi/A} \,.$$

Here V_w is the speed of the surface current, ρ is the density of the sea water, and ω is the angular velocity of the Earth. The motions were

considered in a plane of infinite extent with winds of constant velocity having blown for a very long time.

The structure of Ekman's pure wind drift currents shows that for the sea surface ($z = 0$), $u = V_w \cos 45°$ and $v = V_w \sin 45°$. Therefore the surface current points in a direction of 45° relative to the wind. In the Northern Hemisphere the surface water moves in a direction that is 45° to the right and in the Southern Hemisphere 45° to the left when looking in the direction towards which the wind is blowing. For positions below the surface, the current speed decreases exponentially with depth and varies in direction. Ekman's schematic representation of a pure wind current in the Southern Hemisphere is shown in Figure 1.

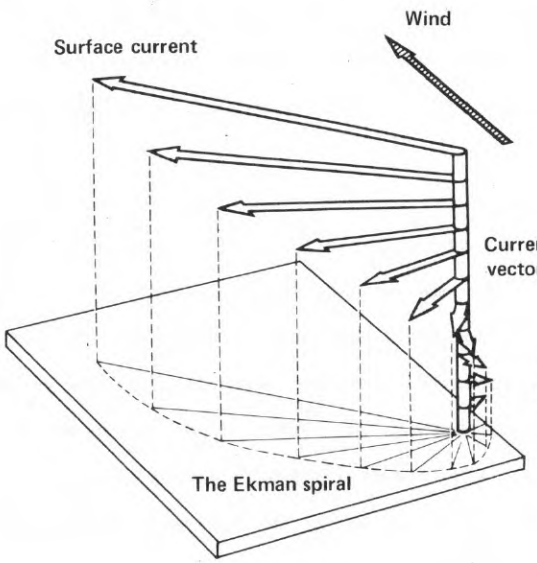

FIGURE 1 THE EKMAN SPIRAL : A SCHEMATIC REPRESENTATION OF A WIND DRIVEN CURRENT IN DEEP WATER IN SOUTHERN HEMISPHERE

Projected on a horizontal plane, the end points of the vectors lie on a logarithmic spiral called the Ekman spiral. At a depth $z = D$

$$u_D = V_w e^{-\pi} \cos(45° - \pi),$$
$$v_D = V_w e^{-\pi} \sin(45° - \pi),$$

so the current vector has decreased to the value $e^{-\pi}$ times the surface speed and the current direction is directly opposite to the surface current direction. The depth D is called the depth of frictional influence.

Strictly according to Ekman's derivation, D becomes infinite at the equator. However we must consider the fact that Ekman assumed that his ocean was infinitely deep, and even the deepest ocean on the Earth cannot satisfy the bottom boundary conditions he assumed.

OCEAN CURRENTS AND NAVIGATION

The direction and velocity of surface ocean currents were at first determined from the drift of ships which currents had thrown off their course. Derelict ships, which seamen came upon for many years, also gave an idea of the direction of the currents.

A hundred and fifty-seven drifting derelicts were found in the North Atlantic Ocean from 1887 to 1909. In 1910, Captain Hartreux made a special study of these derelict drifts and it is part of one of his charts which is reproduced in Figure 2. The danger from these masses of wood and steel, often floating with very little freeway, led the United States in 1908 to build a special vessel to tow derelicts worth salvaging into port and to destroy the others. In the study made by Hartreux he concluded that most of the distance travelled by the derelicts was due to wind which makes their travels of less interest as indicators of surface currents than are the journeys of drift bottles and drift envelopes.

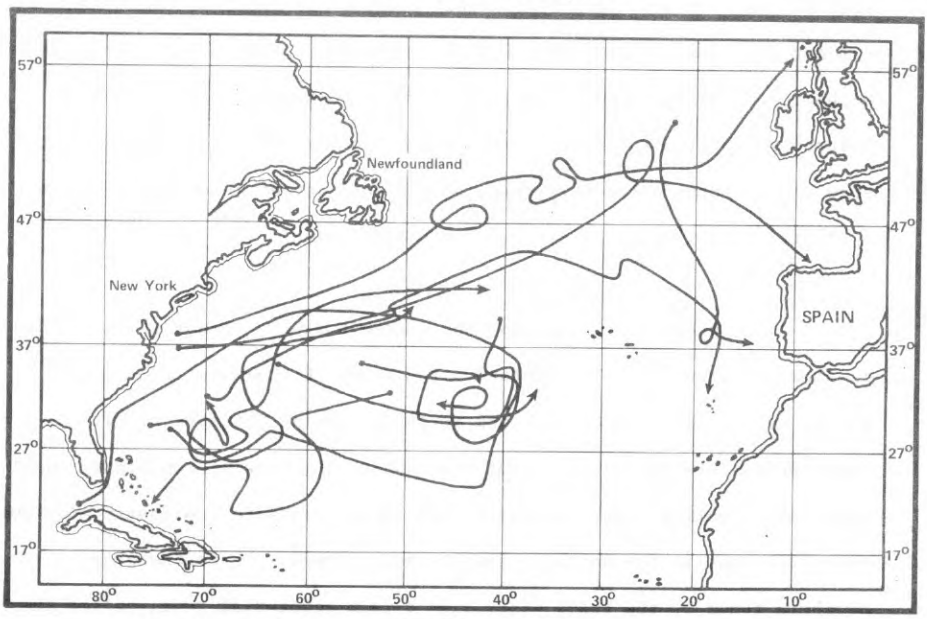

FIGURE 2 DRIFTS OF 10 OF THE 53 DERELICTS TRACKED DURING THE PERIOD 1886–1893

Of special interest is the drift of the half-wrecked sailing vessel *Fanny Wolston*, the travel of which gave evidence of a slow circulating motion of the waters of the Sargasso Sea. In 1891, following a gale, the crew abandoned the schooner not far from Cape Hatteras in North America. In the following three years she was seen forty-six times in various parts of the Atlantic. In July 1892 she was sighted off the Azores where she remained until February 1893 zig-zagging to and fro under the influence of the winds and the changeable currents of the area. She then drifted back toward America and from December 1893 to February 1894 she made to-and-fro movements between Cape Hatteras, Bermuda and the Bahamas. After this time she was carried north-eastward by the Gulf Stream, finally sinking in October 1894 after having described a great ellipse and several smaller circuits totalling nearly 8,000 miles.

Mariners were familiar with the effect of sea currents many centuries ago. For instance, Columbus, who sailed to America in the stream of the North Equatorial Current, has been quoted as saying that the water "moved westwards together with the sky". And in the 1760's mariners from the United States knew of the existence of the Gulf Stream; on their way from America to England they sailed with it, while on their homeward run they steered clear of it. As a result they crossed the Atlantic Ocean much quicker than the vessels under English captains. This was noticed by the authorities and Benjamin Franklin, then U.S. Postmaster-General, was instructed to find the reason. After questioning the seamen involved, he drew up the first scientific chart of the Gulf Stream which was shown as a mighty river flowing across the North Atlantic.

A chart showing the main surface currents in the oceans of the world is shown in Figure 3. The surface circulation of ocean water is caused mainly by the wind. The South and North Equatorial Currents in all the major oceans are due to the trade winds which are blowing constantly in a westerly direction, from the south east in the southern hemisphere and from the north east in the northern hemisphere. Between the southern and northern zones of the trade winds lies a calm equatorial zone, called the

doldrums. In the Pacific Ocean part of the water brought to the coast of the Indonesian Archipelago by the South Equatorial Current flows back forming the powerful Equatorial Counter Current running eastwards. Part of the North Equatorial Current starts off the warm Kuroshio Current which washes the shores of Japan and part of the South Equatorial Current turns south at the east coast of Australia to join the Antarctic Circumpolar Current below New Zealand. The South Equatorial Current in the Atlantic Ocean piles up the water on the east coast of Central America where it splits into two branches, one heading south along the coast of South America to join the Antarctic Circumpolar Current and the other joining the North Equatorial Current which makes its way into the Gulf of Mexico. The water which runs into the Gulf raises its level and forces it out into the North Atlantic Ocean through the Florida Strait. The speed of this Florida Current reaches 6 miles per hour in the surface layer. Travelling north and then north-east this water joins the Gulf Stream.

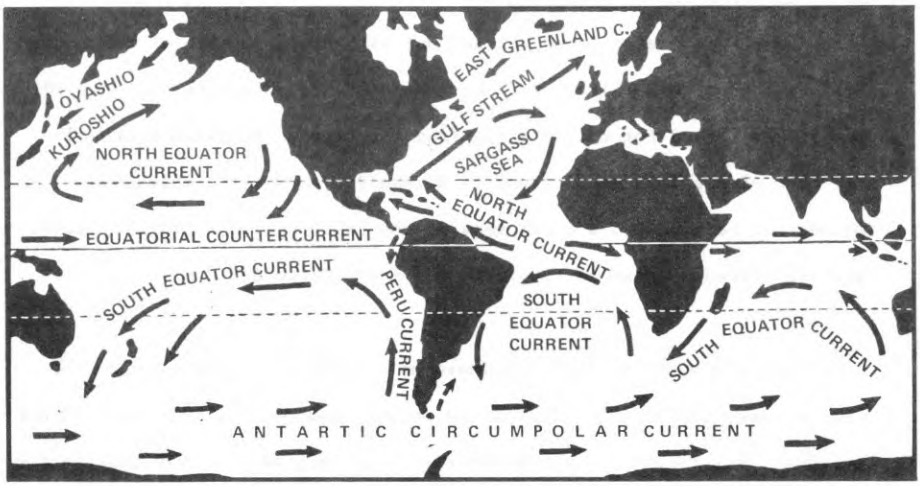

FIGURE 3 MAJOR SURFACE CURRENTS OF THE WORLD

The Gulf Stream and the Kuroshio are warm currents; the former heats the whole of Northern Europe and the latter the Japanese coast. In 1911 a bill was submitted to the United States Senate to build a vast dam that would prevent the Gulf Stream from flowing to the shores of Europe and would deflect it to the north coast of America. Fortunately, the bill was

rejected. Had the project been carried out, not only would the European climate have become colder but the climate of the United States Atlantic coast would hardly have become warmer. The nearness of a warm current and a cold land would, in winter, have created sharp gradients of atmospheric pressure and given rise to cold storm winds blowing seawards.

Besides the warm ocean currents flowing toward the poles there are cold ones which carry water towards the equator. The East Greenland Current carries water with ice-floes and ice-bergs from the Arctic basin into the North Atlantic. The Oyashio comes from the Bering Sea and meets the Kuroshio in the south. The cold Peru Current travels along the west coast of South America and a similar cold current, known as the Benguela Current, washes the west coast of South Africa. These cold Peruvian and Benguela Currents originate in the Antarctic Circumpolar Current which travels in an easterly direction south of Australia.

DRIFT EXPERIMENTS OFF GREAT BRITAIN

A well known experiment carried out with drift bottles in the North Sea was that of Dr. Fulton over the years 1894-7. His work was done for the Fishery Board for Scotland and from the results supplied by the 16 per-cent of his 2074 bottles and 1479 labelled wood slips which were recovered, he produced a chart showing the existence of a great cyclonic surface current system in the North Sea (see Figure 4).

Fulton's work has been continued on a large scale right up to the present time. Up to 1950 Scottish scientists had put out more than 53,000 bottles. The results of these experiments, which were mostly made in the northern North Sea, have been the subject of a number of reports by Dr. Tait of Aberdeen. His reports have shown the seasonal fluctuations in the strength of the ocean current which passes through the Faroe-Shetland Channel into the North Sea and the existence of great eddies in this Sea.

In addition to drift bottles, plastic envelopes have been used on a large scale since the conclusion of the Second World War for the same

purpose. Scientists in Britain have used them in the North Atlantic Ocean to find out something about the spread of fuel oil with which ocean tankers often contaminate the ocean and the beaches of Western Europe, and endanger the lives of countless sea birds.

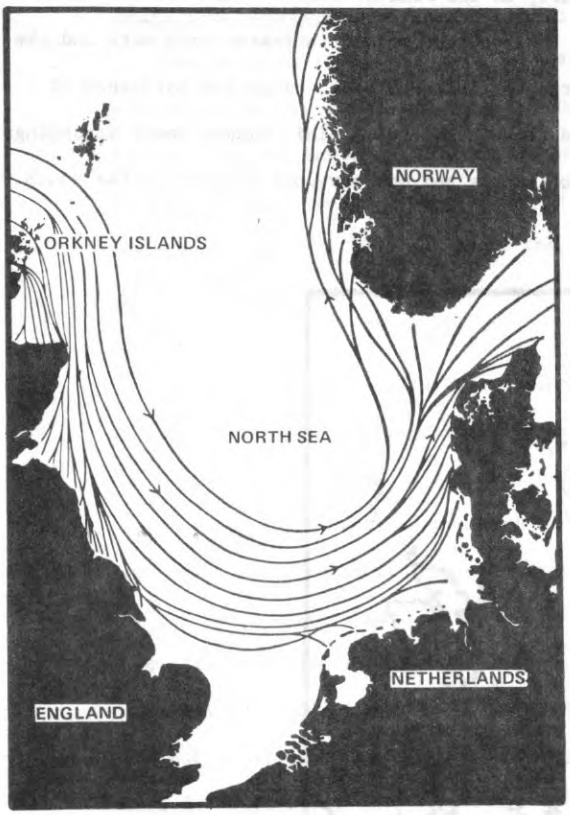

FIGURE 4 RESULTS OF FULTON'S DRIFT BOTTLE EXPERIMENTS IN THE NORTH SEA

For instance, the National Institute of Oceanography in Surrey uses watertight plastic envelopes containing printed cards requesting the finders to return them to the Institute with information about the date and place of their discovery.

In 1954 three successful drops of envelopes were made along predetermined tracks running from the Bay of Biscay to the Faroes. Figure 5 shows the effect of the wind observed aboard Ocean Weather Ships at stations *India*, *Juliett* and *Kilo* during the first six months after each drop was made, upon the behaviour of the drift envelopes liberated in the first drop.

After this drop the southerly wind at *India* brought envelopes ashore in Southern Iceland, but the average wind for the period was westerly, hence the wide spread and north easterly mean direction in sub areas 1 and 2. To the southward, across the main body of the Drift, the spread decreases and the mean direction is due east, as the wind at *Juliett* was from the west. In the sub areas 6, 7 and 8 however, the spread increases once more and the mean direction gradually turns to the south east, under the influence of the west-north-westerly wind sequence at *Kilo*. This caused heavy strandings along the coast of the Bay of Biscay and one envelope beached as far south as Lisbon.

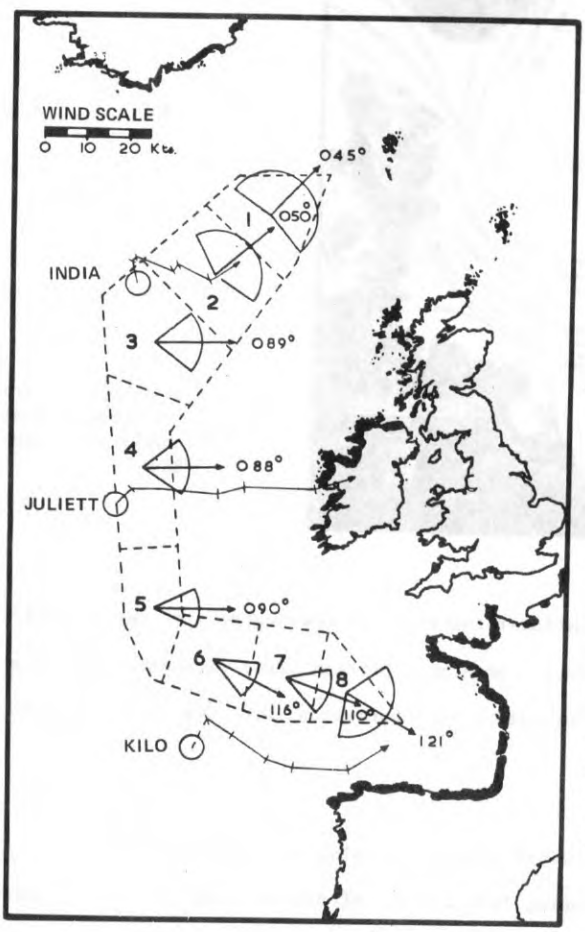

FIGURE 5

DROP I OF THE NATIONAL INSTITUTE OF OCEAN-OGRAPHY EXPERIMENT IN THE NORTH-EAST ATLANTIC IN 1954. THE SECTOR IN EACH SUB-AREA SHOWS THE SPREAD OF ENVELOPES AND THE ARROW THE MEAN DIRECTION OF THE DESTINATIONS. THE LINKED VECTORS SHOW THE MONTHLY AVERAGE WINDS AT THE THREE WEATHER SHIPS

This experiment provides further evidence of the strong influence which the wind exercises upon the currents and to what degree it can upset the

accepted pattern should it blow from unusual directions or in unusual sequences. It is impossible to get a relationship between drift speed and wind speed from this experiment, but it gives a general idea of what might happen to oil slicks and so on.

DRIFT EXPERIMENTS IN THE SOUTHERN OCEAN

As early as 1902, Dr. Bruce liberated a number of drift bottles to determine the direction and speed of the surface current in the Southern Ocean. Two bottles were found in Victoria and at least one reached New Zealand only to remain undiscovered for 50 years. In September of 1952 it was found more than 200 feet above the present high-water line some three miles south of Rangitiki River in North Island.

Figure 6 shows results of surface drift experiments in the Southern Ocean carried out by the Flinders University of South Australia and reported on in August 1970. During the last half of December 1969 three batches of 1,000 cards each were released from the Japanese Ice-breaker *Fuji* at 40, 50 and 60°S and approximately 110°E. By the following August cards from two of the three batches had been found. Forty three cards released from a position 40°S and 115°E had arrived on the south-west coast of Western Australia, the first arriving in the middle of March, some 87 days later and 600 miles from their release point. These cards gave a minimum mean surface drift speed of 0.25 knots or 13 cm/sec.

In contrast to the north-east drift of these cards, some of the group released three days later at 50°S, 110°E drifted quickly eastward so that two of them arrived approximately 129 days later and 2,000 miles away at Macquarie Island; their mean speed was about 0.6 knots or 29 cm/sec. By August a total of thirteen cards from this batch had been found on this small island which is less than 20 miles long. None of the batch from 60°S had been reported found.

Batches of 500 cards were also set free along the longitude 132°E between Australia and Antarctica from the U.S. Navy oceanographic ship *Eltanin* during

the summer of 1969-70 (see Figure 7). Most of them were released close to the Australian mainland; however, two cards from a group released at 50°S on New Year's Day also arrived at Macquarie Island. The first of these was found 104 days after release having travelled 1,150 miles at a speed greater than 0.4 knots (21 cm/sec.). Two cards of another group, drop D24, released at 45°S on January 20th, 1970, were found five months later near Hobart having drifted some 730 miles with a mean speed greater than 0.18 knots (9 cm/sec.) in a north-easterly direction.

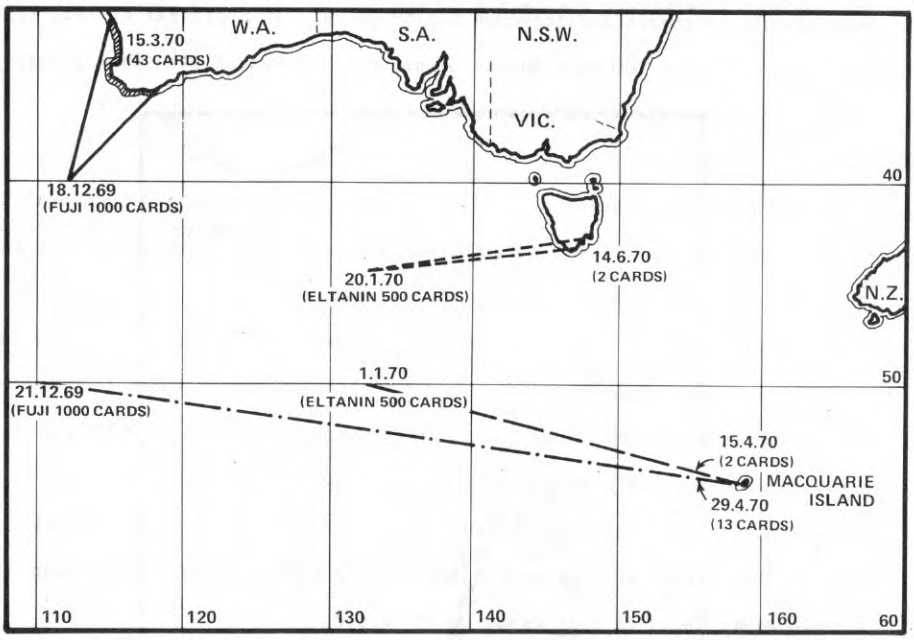

FIGURE 6 SURFACE DRIFT IN THE SOUTHERN OCEAN SOUTH OF AUSTRALIA

Compared to the relatively fast and probably fairly direct drift to Macquarie Island, the motion of cards closer to the south coast of Australia is much slower and more random. In fact, some cards released within 250 miles of the coast were not found until some strong westerly storms blew them ashore some four months later.

The existence of north-west long-shore currents in the region west of Kangaroo Island seem to be confirmed by the north-westward motion of floats released south-west of Kangaroo Island at 132°E and 37°S (drop D26).

Some of these floats found their way to Mt. Hope and Port Lincoln, on Eyre Peninsula and others found their way onto the north shore of Kangaroo Island and even into St. Vincent's Gulf.

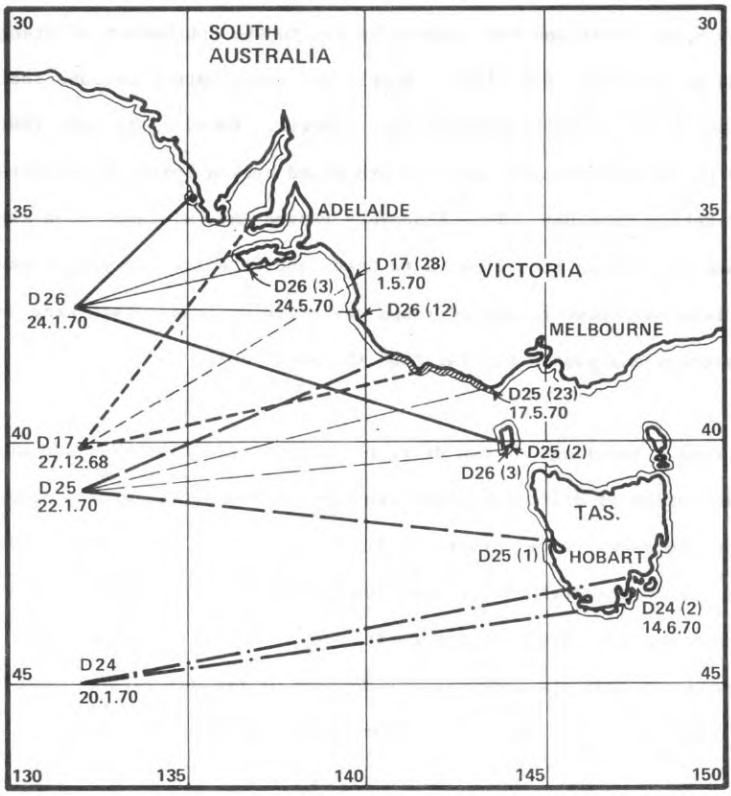

FIGURE 7 SURFACE DRIFT FROM DROPS OF 500 CARDS MADE ALONG A LINE 132°E SOUTH OF SOUTH AUSTRALIA. THE SYMBOLS D25(23) 17.5.70 INDICATES THAT 23 CARDS FROM THE BATCH D25 WERE RECOVERED ALONG THE SHADED STRETCH OF COAST, THE FIRST BEING PICKED UP ON 17 MAY 1970

Most of the cards released close to the mainland by the *Eltanin* were found progressively further eastward with the passage of time as the prevailing westerly winter winds had a longer time to act. Several of a batch released at 41°S on January 22nd (drop D25) arrived on King Island in Bass Strait after more than 130 days, giving a mean drift of at least 0.18 knots (9 cm/sec.). Later still some were found on the coast of Tasmania, west of Strahan. This barren coast is nearly uninhabited and may well have been the landing point of many more drift cards not yet picked up.

SOME INTERESTING CASES OF DRIFT

A derelict which added greatly to knowledge of Arctic currents was *La Jeannette*. She passed through Bering Strait in order to make a study of the Polar Basin and was trapped by ice to the south-east of Wrangel Island on September 6th, 1897. Nearly two years later, in June 1881, she sank north of the archipelago of New Siberia. However, in July 1884, Eskimos found on the easternmost parts of Greenland broken boxes of biscuits and other debris from her. This discovery proved the existence of a marine surface stretching from Siberia to Greenland; the ice carrying these materials must have travelled round the north of Franz Josef Land and Spitsbergen and passed not far from the North Pole.

From a knowledge of the drift of *La Jeannette's* stores, and upon a consideration of drifts of other wreckage in the Arctic Ocean, Nansen decided to make the celebrated drift in the vessel *Fram*. After being frozen-in to the north of the New Siberian islands on September 29th 1893, the *Fram* drifted slowly to the north-west with the ice and by the beginning of 1896 she was within 4 degrees of the North Pole. She broke free from the ice on June 28th 1896, to the north of Spitsbergen.

The Soviet ice-breaker *Sedov* is famed for the following great drift in the ice of the Arctic Sea. After being frozen-in in the Laptev Sea on October 23rd 1937, fifteen of her crew volunteered to remain aboard. She drifted first to the north and then to the east, through a region not explored up to that time, for more than three years before breaking from the ice.

It is also of great importance to know everything possible about the drift of free ice-bergs in seas frequented by shipping. The tragic loss of the *Titanic* in 1912 led to the organisation of the present day Ice Patrol which reports the movement of arctic ice-bergs which drift as far south as the Azores in the North Atlantic Ocean. Less well known is that oceanographers in the U.S. Coast Guard periodically prepare charts of currents, based upon hydrodynamical computations, in order to help them predict how ice-bergs will travel.

Probably the most publicised ocean drifts of all time were those accomplished by Thor Heyerdahl and his companions, firstly across the Pacific Ocean on the balsa-wood raft *Kon-Tiki* and then across the Atlantic Ocean in the reed boat *Ra II*. Though Heyerdahl used the winds in that both his vessels had sails of a sort, much of his progress in both cases was in the nature of a drift. Less well known is the fact that some 40 years before these drifts, Franz Römer crossed the Atlantic alone in a collapsible rubber boat, a feat of courage and endurance far exceeding any similar adventure reported since.

Finally, it is of interest to note that during the years 1560 to 1800 any person who uncorked a bottle washed ashore on the coast of Britain could have been punished by hanging. This situation arose when, in 1560, a boatman found a sealed bottle on Dover Beach. Being illiterate he took the message he found inside to the local judge. It turned out to be a secret report saying that the Dutch had seized the Russian Arctic Island of Novoya Zembya. After this incident Queen Elizabeth appointed an official "Uncorker of Bottles" and until this office was abolished in the reign of King George III, any unauthorised person who opened a bottle brought ashore by the sea was committing a capital offence.

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STORM DAMAGE TO THE ADELAIDE FORESHORE

by

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In an article titled "Setting for Disaster" in the Advertiser Saturday Review of July 8, 1972, science reporter Barry Hailstone wrote:

Just about every year Adelaide's foreshore threatens to become a disaster zone. High water pounds explosively against concrete sea walls, splintering them like pieces of balsa wood. Front lawns, gardens and retaining walls slip suddenly seaward - leaving houses perched perilously close to foreshore sandy cliffs.

But the seas, because of our geography are never really rough and although our winds are gale-force they are rarely really wild. Instead, it is a strange potpouri of tides, wind, sandless beaches, low barometric pressure, concrete walls, roads on the beachfront and an absence of sandhills that brings annual destruction .....

Last Wednesday's seafront damage, like the majority of the world's coastal catastrophes, was caused by storm surge. This is a marked increase in the level of the sea as a result of wind piling up seawater along the coastline. Seawater flooded drains and streets and low lying areas of Port Adelaide ..... Last Wednesday's north-west wind, which had its greatest average speed only 25 knots, caused a rise of four feet in the sea level along the coast. Combined with it were the effects of a low barometric pressure, which also causes the sea to rise, and a high predicted or astronomical tide. At 5.10 p.m. Port Adelaide had its second-to-highest tide on record. At 13 feet - four feet above the predicted tide - it was only two inches lower than the record tide of May 12, 1960.

The weather system of June 28 last year which brought about this situation is shown in the Synoptic Weather Chart of Fig. 1. At 9 a.m. an intense low pressure system of 29.10 inches had moved in from the west and was situated about 350 miles south of Kangaroo Island. A cold front running parallel to the West Coast had reached Neptune Island, where 40 knot winds were reported. At this time Adelaide recorded a barometric pressure of 29.53 inches which gradually fell to a minimum at 2 p.m. At 9 a.m. the average wind at Adelaide was 15 knots NNW which gradually increased to an average speed of 27 knots NW just before 3 p.m. Until

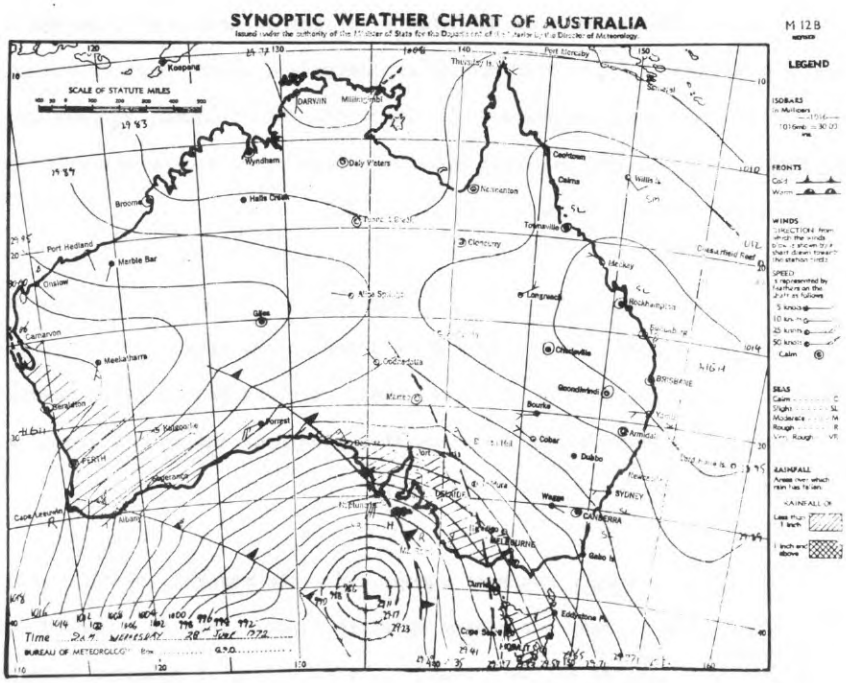

Figure 1. The weather map for Australia at 9 a.m. June 28, 1972.

8 p.m. the average speed fluctuated between 18 and 25 knots and its direction slowly veered to the west, after which its strength began to fall.

This system caused the storm surge of four feet referred to earlier, which enabled the sea to damage structures normally well out of reach of the water. Storm surges may cause damage both directly and indirectly. Very high sea levels can cause overtopping of embankments and flooding of

low-lying land, can undermine foundations of houses and club-houses built on the shore and submerge jetties and wharves. The level of the Port River was only a few inches short of covering the wharves and flooding the storage sheds at Port Adelaide during the storm. In addition, waves larger than usual because of the stronger winds, can reach sea-walls and shelter sheds

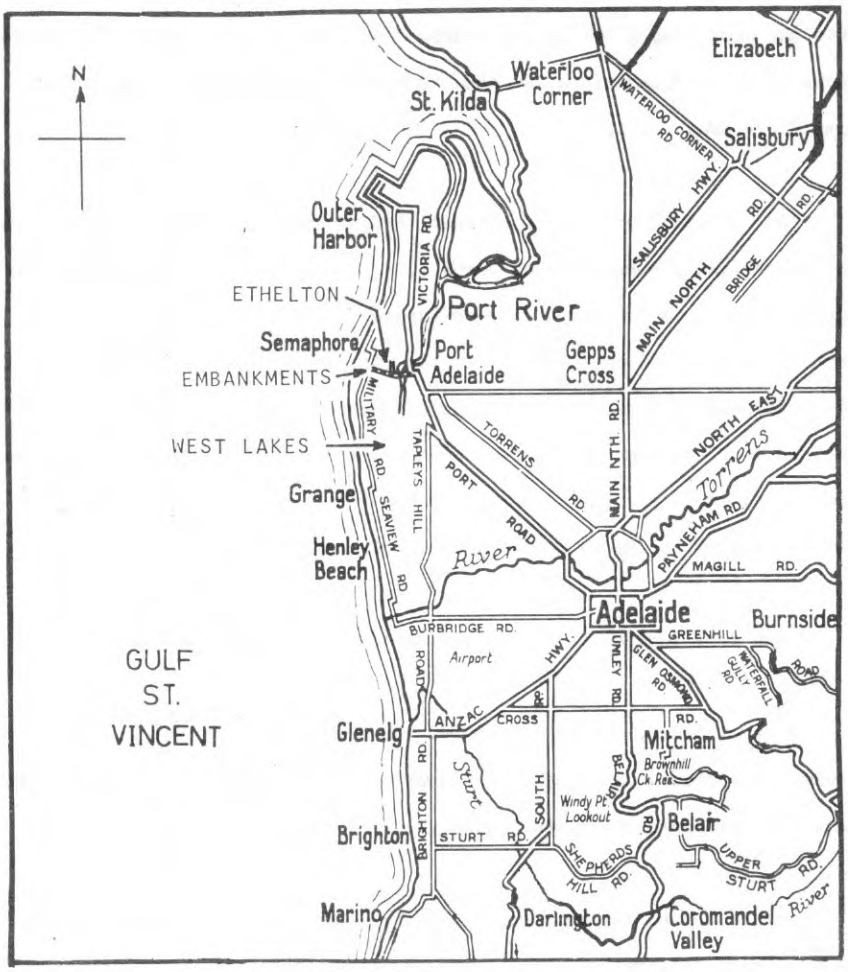

Figure 2. Map showing the Adelaide foreshore from Marino to Outer Harbor.

and smash explosively against them, damaging them by their impact or by eroding away the sand under their footings. At low tide these waves would dissipate their energy by breaking and running up the sloping beach.

An excellent summary of the effect of this storm was printed in the News on June 29, 1972.

Angry seas, whipped by gale force winds, have devastated Adelaide's beachfront ..... .

Along the Adelaide foreshore (see Fig. 2), *reinforced concrete retaining walls at Broadway, Glenelg, have been shattered and dragged back into the sea .... . The approaches of Brighton jetty are collapsing and a 25 ft. bite has been gouged out of the nearby road. The kiosk at Seacliff has been ripped off its foundations, smashed to match-wood and flung upon a boat ramp 60 ft. away ..... .*

The esplanade off Downing Street, Brighton, is closed by council signs and undermined for hundreds of yards ... . Large sections of the bitumen tarmac leading to the jetty have collapsed ..... . The sides of the sea front road are falling into the sea for 150 yards north to a wooden kiosk which has had its steps and sections of decking torn away by last night's furious sea. Workmen are pouring sand and rocks into a huge pit where the sea has eaten 25 ft. into the road next to the jetty. At times last night the sea end of the jetty was completely covered by water.

Seas were lapping at the guttering of shelter sheds at Seacliff .....

At West Beach, damage is severe. An embankment has been scoured back towards the road up to 30 ft. in places. A 200 ft. section of the foreshore wall has collapsed on to the beach.

Damage around the metropolitan coast is certain to run into hundreds of thousands of dollars.

SOME REPORTS OF STORM DAMAGE

A search of the local newspapers from 1948-1972 revealed much about the nature and extent of the foreshore damage caused by storms. In many of the cases which follow, extracts have been taken directly from the news articles. The first case considered is the now famous (or infamous?) storm of 11 April, 1948, during which the naval frigate Barcoo was blown aground. This storm was reported as follows:

1948 April 11

Glenelg Jetty Total Loss

Unroofing of homes and buildings, and the shattering of windows and fences was particularly marked along the foreshores, which were strewn for miles with wreckage of the Glenelg jetty and wrecked small craft .....

(Advertiser 12/4/48)

£1 Million Storm Damage: Bay Loss £250,000

Damage in yesterday's hurricane of unparalleled violence is likely to exceed £1,000,000 over the relatively narrow path the storm took across the State.

At Glenelg alone, which from today's reports appeared to bear the main brunt of the 80 m.p.h. winds, damage is estimated at between £250,000 and £300,000.

The naval survey frigate Barcoo, which went aground between Glenelg and West Beach just before dawn yesterday, was still upright today in very light seas.

(News 12/4/48)

Throughout this storm the winds were from the SW. The greatest average velocity of 55 knots occurred about noon when the storm surge was greatest (about 4.3 ft.); it then fell away until 4 p.m., after which it remained at a steady 40 knots. At 6 p.m., when the astronomical tide was at its peak of 9.1 ft., the storm surge was only 1.1 ft., resulting in a total tide height of 10.2 ft. Had the maximum surge occurred at this time instead of at low water, the total tide height would have reached 13.4 ft., a figure

2 inches above the record level of June 12, 1960.

1953 May 18

£1 Million Gale Toll: Coast takes worst battering in memory.

It is estimated £1 million damage was done by the terrific seas that smashed against the S.A. coastline yesterday and all last night. A 70 m.p.h. gale whipped up the highest tides for 38 years. Four metropolitan jetties are badly damaged and two in the country have disappeared.

Seaside engineers said today the coast had taken its worst battering in memory - worse than the 1948 storm. Miles of foreshore today looked as if it had been under artillery bombardment, with gaps of hundreds of feet slashed in seawalls, embankments, and roads.

And the metropolitan coastline will again face a crucial test at 6 o'clock tonight when the tide is again at its peak.

(News 19/5/53)

1955 August 6-10

During this period a series of storms lashed the Adelaide foreshore. Table 1 compares the barometric pressures, wind speeds, recorded and predicted tides for these five days with the corresponding figures for the May 18 storm in 1953. In the 1953 storm the maximum surge of nearly 4 ft. coincided with the astronomical high water, whereas throughout this series of storms the maxima occurred near times for low water.

TABLE 1

Date	Barometer (inches)		Wind (m.p.h.)			Recorded Tide (ft.)		Predicted Tide (ft.)	
	Min.	Max.	Min.	Max.	gust	Low	High	Low	High
6.8.55	29.53	29.82		60	NW		10.9		9.0
7.8.55	29.39	29.67	15	72	NW	4.3	11.2	2.3	8.9
8.8.55	29.43	29.58	20	55	W	5.8	11.2	1.9	8.6
9.8.55	29.39	29.80	10	58	W	5.0	12.0	1.9	8.6
10.8.55	29.73	29.85	5	40	NW	3.3	9.4	2.0	8.7
18.5.53	29.48			67	W		12.6		8.7

1956 June 12

Abnormal Gulf Tides: Flooding, Damage on S.A. Coast.

Backed by strong westerly winds, abnormally high tides from 3 ft. to 5 ft. above predicted levels, caused flooding at a number of points along the eastern coasts of Spencer Gulf and St. Vincent's Gulf last night.

Last night's high gulf tides and west wind caused minor damage along Adelaide's seafront. At Birkenhead, one of the highest tides since 1948 flooded acres of low-lying factory and residential land to a depth of 6 inches. Water swirled 9 inches deep into Searles' enclosed slipway near Birkenhead Bridge, rising to within 3 inches of the record water height recorded in 1948... .

High tide at Port Adelaide had been officially predicted at 8 ft. 8 in., but it was estimated last night at about 12 ft. Yards a quarter of a mile from the river were inundated by water backing inland up storm drains. Water covered the Port Adelaide Yacht Club car park 18 in. deep ..... . The tide would have risen dangerously higher if the wind had not dropped.

At Outer Harbor, the tide could not be measured as it exceeded the 12 ft. gauge, but it was estimated at 13 ft., one of the highest tides for some years. It had been officially predicted at 8 ft. 8 in. ..... .

Unusually high tides were recorded at Port Germein and Port Pirie last night. At Port Pirie the reading was 13 ft. 6 in., and at Port Germein it rose to 13 ft.

(Advertiser 13/6/56)

1960 May 12

Heavy Damage to S.A. Beaches

Adelaide's seafront and S.A. outports last night took their worst battering since 1948 through an exceptionally high tide whipped up by a 70 m.p.h. wind. The storm equalled in intensity the hurricane that devastated the suburban foreshores in 1948.

Parts of Lefevre Peninsula were cut off for more than an hour last night from the rest of the city by floodwater forced back by the tide along storm water channels.

At Glenelg yesterday sea water poured feet deep across the car park and formed a lake on Wigley Reserve. Water 2 ft. deep washed through the Glenelg Sailing Club premises. The sea poured over the esplanade and flooded the lower end of Broadway, South Glenelg, to a depth of 3 ft, sea water reaching the verandahs of several homes.

When the tide was at its highest, parts of Semaphore and Largs Bay jetties were submerged.

The tide banked up in the Port River and flooded nearby streets. It flowed across Nelson Street into St. Vincents Street. There was water 4 ft. deep at each end of the Birkenhead Bridge. Military Road, Grange was 3 ft. under water and houses at Port Adelaide were flooded when the Port Adelaide Canal overflowed.

The tide at Port Adelaide and Outer Harbor was described by shipping authorities as the highest there for years. It covered the tide level gauges at Outer Harbor and was estimated to reach at least 15 feet.

(Advertiser 13/5/60)

73 m.p.h. Gale Batters State's Seaboard

Destruction exceeding the £250,000 hurricane havoc in 1948 may have resulted from the vicious storm which ripped along the S.A. seaboard last night.

Harbors Board general manager, Mr. Carl Meyer, said: "We were lucky to come through as lightly as we did. A tide, believed to be an all-time high, with the high winds could have caused much greater damage."

(News 13/5/60)

In fact, the tide that evening was the highest ever recorded on the Adelaide foreshore, viz. 13.2 ft. at 6.10 p.m. The maximum wind gust for Adelaide during the storm was 61 knots from WSW.

1964 July 12-17

A series of storms buffeted Adelaide during this period; the strongest wind gust ever recorded occurred in this time, as well as the lowest recorded barometric pressure. A number of oil tankers were hove-to in the gulf for nearly a week unable to berth to load and unload their cargoes at Port Stanvac. The following excerpts from newspapers give details.

State Buffeted for 3 Days

Several ships were delayed in their arrivals at Port Adelaide while three oil tankers have been forced to remain several miles offshore from the Port Stanvac oil refinery.

One of the tankers, the 96,000 ton Esso Bayern, which is carrying crude oil for the refinery, has been prevented from berthing since Thursday. It is the second time within three weeks that oil tankers have been forced to heave-to for up to a week by bad weather .....

At Port Pirie last night a high tide whipped by strong winds along Spencer Gulf caused seawater to flood back through drains.

(Advertiser 13/7/64)

Hurricane Hit 92 m.p.h.

Adelaide today was lashed by a 92 m.p.h. hurricane - the strongest ever recorded in Adelaide. During a weekend of wild storms the barometer fell to the lowest reading registered in Adelaide - 29.1 in.

The previous highest wind on record was 81 m.p.h. on November 19, 1962, and on April 11, 1948, when the Glenelg jetty was destroyed. Previous lowest barometer was 29.12 inches on November 5, 1951.

(News 13/7/64)

Tankers Still Not Berthed

Three tankers which have been unable to berth at the oil refinery at Port Stanvac for nearly a week because of strong winds and high seas will be joined by another tanker today.

The 96,000 ton (dead-weight) tanker Esso Bayern, with crude oil from the Persian Gulf, and two 20,000 ton tankers which loaded refinery products, had been standing off Port Stanvac waiting for seas to moderate since late last week. The Mobil Daylight, also of 96,000 tons (dead weight) was due off the refinery from the Persian Gulf today.

(Advertiser 17/7/64)

1965 June 2

Gales Lash S.A., Cause Havoc

Fierce winds buffeted S.A. yesterday, causing widespread damage and lifting tides to a dangerous level. Two aircraft had to be diverted, a ship was forced to stay in port, a fishing cutter was wrecked, and two country power supplies were interrupted.

Driven by strong winds, waves up to 10 ft. high pounded metropolitan beaches late yesterday afternoon and last night.

The Signal Station at Outer Harbor last night attributed the abnormally high tides to the strong winds. High tide at the station just after 5 p.m. was 11 ft. 9 in. - 2 ft. 6 in. higher than predicted. A spokesman for the Bureau of Meteorology said that gale-force south and south-westerly winds had whipped up the unusually high tide. The high tide in the Port River forced water back into drains, causing flooding in Nelson and St. Vincent Streets, Port Adelaide. Water also covered a car park near the Birkenhead Bridge to a depth of about 1 ft. ..... .

There was a tide of 8 ft. at Port Lincoln and the town's harbormaster (Capt. G.F. Pickhaver) said that this was 2 ft. higher than predicted. Rain, hail, an electrical storm and winds estimated at 40 knots, formed Port Lincoln's weather pattern..... .

There was an abnormally high tide at Port Pirie last night. The predicted level of 10 ft. 9 in. at 8.21 p.m. had been exceeded by three feet by 7.21 p.m. The high tide covered Fisherman's Jetty, the mooring point for the city's fishing fleet, and water ran back through storm drains and flooded water tables in Florence Street, a main thoroughfare. In other places water covered footpaths and even fences.

(Advertiser 3/6/65)

1965 November 11

Wide Damage by Wind and Hail.

Violent winds and hail caused widespread damage throughout S.A. yesterday. It was Adelaide's coldest November day since 1916. Unusually high tides and big seas caused damage and, at Adelaide Airport, a maximum wind gust of nearly 80 m.p.h. was measured ..... .

Seas washed away an estimated 20,000 tons of sand - to a depth of about 4 ft. - at Glenelg, and several craft in the boat haven broke from their moorings .....

The Henley and Grange swimming pool, which has been pounded for days by heavy seas, has been seriously damaged. At high tide yesterday morning two fractures formed in the retaining wall in the south-west corner of the pool. The cracks were wide enough to see through. The floor of the pool also collapsed in that section.

(Advertiser 11/11/65)

METEOROLOGICAL EFFECTS ON SEA-LEVEL, 28 JUNE 1972

The predicted and recorded tide at Inner Harbor on the Port River at Port Adelaide for the period 600 hrs. June 28 to 900 hrs. June 29, 1972, are shown in Fig. 3. The regular rise and fall of sea level caused by the systematically varying gravitational forces of the sun and moon acting on the land and oceans of the earth, is the predicted astronomical tide shown. The figure shows that a very high level of 2.8 m (9.2 ft.) was predicted for 1756 hrs (5.46 p.m.) on June 28. The recorded tide, which is the sum of the astronomical tide and the

storm surge (or meteorological tide, see Ref. 1), shows that the storm had raised the river level at Inner Harbor 0.6 - 1.2 m (2 - 4 ft.) that day. The highest level was reached a little after 5 p.m. (1712 hrs., marked A in Fig. 3) when the storm surge was 1.2 m (4 ft.); the recorded tide was 3.95 m (13.0 ft.), only 5 cm. (2 inches) below the highest level ever recorded in the river, viz., 4 m (13.2 ft.) on June 12, 1960.

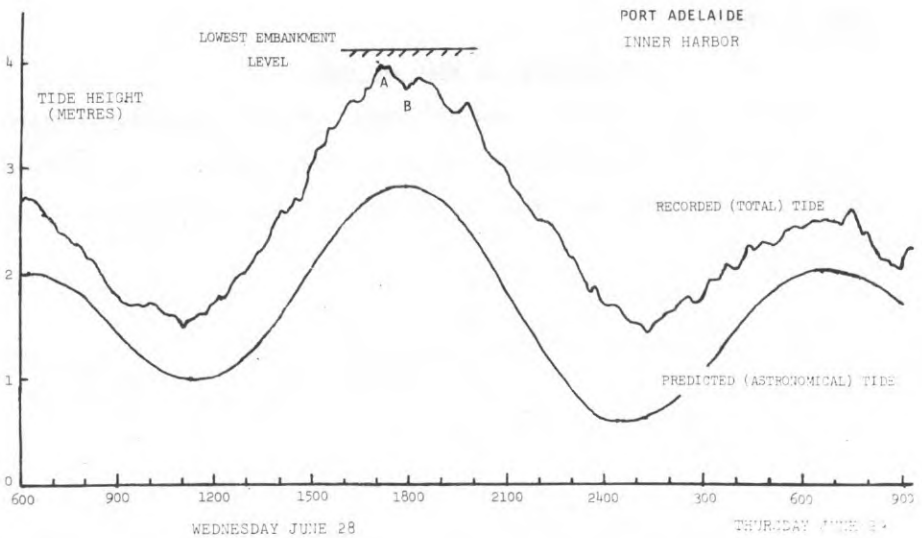

Figure 3. Predicted (astronomical) tide and recorded (total) tide from the S.A. Department of Marine and Harbors tide recorder at Port Adelaide, June 28-29, 1972.

Examination of these records show that the effect of the storm on the river level dropped between 1712 hrs. (5.12 p.m.) and 1800 hrs (6 p.m.) - marked A and B in Fig. 3 - and that the water level in the Port River fell to 3.75 m (12.3 ft.) before rising again. This fall was most fortuitous, because the river level was rapidly approaching the lowest level of the embankments protecting Ethelton and West Lakes. The position of these embankments is marked in Fig. 1; one embankment running north-south on the west side of the river protects houses in Ethelton from excessively high waters, and the Bower Road embankment runs east-west blocking off the upper reaches of the Port River from West Lakes.

The levels given on Fig. 3 show how the river came within 15 cm (6 inches) of overtopping these embankments. It is noteworthy that Ethelton is more prone to flooding by the river than is West Lakes; this is due to local topography and the general levels of the protecting embankments, which would cause the river to pour into Ethelton before it would run into West Lakes, and in Ethelton there is nowhere for the water to drain into from the streets whereas in West Lakes much of the water could run into the lakes.

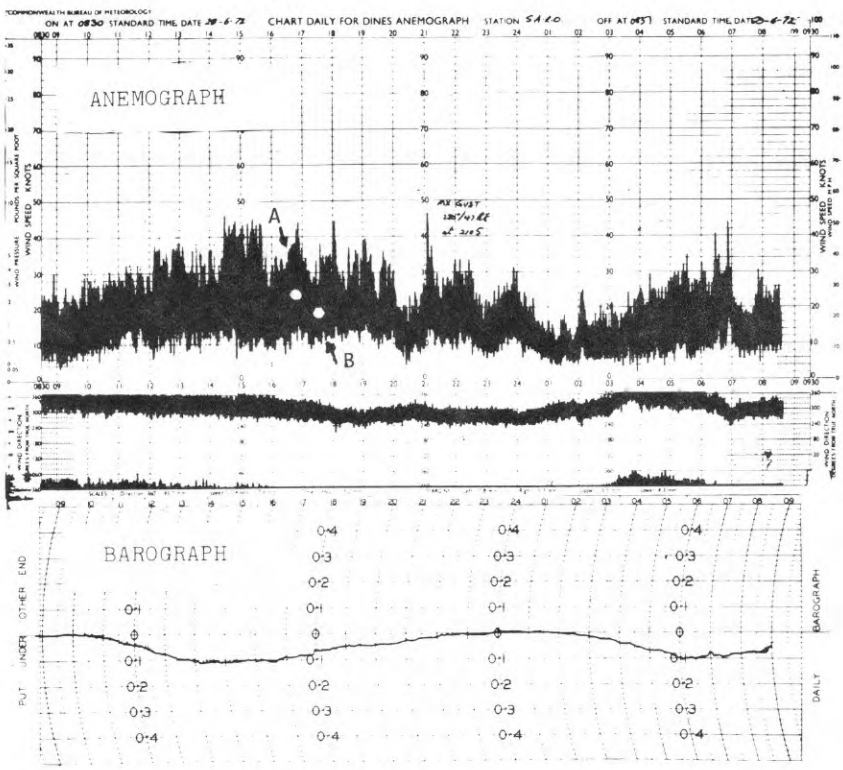

Figure 4. Wind and air-pressure records from the S.A. Regional Office of the Bureau of Meteorology between 900 hrs. June 28 & 900 hrs June 29, 1972.

The cause of the reduction of the storm surge from 1.2 m (4 ft.) to 0.95 m (3.1 ft.) in less than an hour, at this critical time, is clear when the appropriate wind and airpressure records are examined (see Fig. 4). The small increase in air-pressure during this time, including the sharp jump just before 1800 hrs. (6 p.m.), accounts for very little of this drop. Its cause was mostly due to a fall in average wind speed over the gulf waters

near Adelaide between 1640 hrs. (4.40 p.m.) and 1730 hrs. (5.30 p.m.), shown by A and B on the anemograph of Fig. 4. During this time the average speed of the north-westerly fell from 24 knots to 18 knots, before rising once again. Since any increase in sea level at the mouth of the Port River takes nearly 30 minutes to propagate to Inner Harbor, this fall in wind speed was reflected in the reduced storm surge between 1712 hrs. (5.12 p.m.) and 1800 hrs. (6 p.m.). The time lag for the passage of rising water levels up the Port River is seen clearly in the tide predictions of June 28 (see Ref. 2): high water at Outer Harbor was due at 1728 hrs. (5.28 p.m.) while near the head of the river high water was due at Inner Harbor at 1756 hrs. (5.56 p.m.).

RESEARCH INTO STORM SURGES AND BEACH EROSION ON THE ADELAIDE FORESHORE.

A study of meteorological effects on the waters in the South Australian Gulf System of Spencers Gulf and St. Vincent's Gulf commenced in 1971 in the Department of Applied Mathematics at The University of Adelaide. In order to gain a better understanding of the nature of storm surges, the writer and K. Tronson have modelled this problem mathematically using two different approaches.

Firstly, they adapted a numerical model of tidal propagation in the S.A. Gulf System, which was based upon the hydrodynamics of the waters of the region, to incorporate varying air pressures and wind stresses (see Ref. 3). This project is now being extended to include the dynamic effect of increasing wind speeds and changing air pressures as the storms move across the Great Australian Bight and approach Adelaide.

Secondly, various combinations of auto-regressive moving-average formulae have been fitted to approximately 36,000 readings of wind velocity, air-pressure and tide-heights in order to determine the feasibility of finding a relatively simple formula to predict the height of storm surges from weather conditions. Meteorological data for 1969-71 was supplied by the Bureau of Meteorology and consisted of three-hourly readings of wind speed in ranges of three-knots, wind directions read in 16 points of the compass and air-pressure read to the nearest 0.1 millibar. Meteorological effects on the tide were calculated by subtracting astronomical tide

heights, predicted on the CDC 6400 computer at The University of Adelaide, from actual sea-levels recorded by the S.A. Department of Marine and Harbors and read to the nearest 3 cm. (0.1 ft.) every hour.

Successful predictions have been made using two particular formulae (see Ref. 4). One of these predicts the storm surge three hours ahead using air pressures read 12 hours earlier, wind data collected three hours previously and present wind velocity. The other formula predicts the surge three hours ahead using its present value, the air pressure from 12 hours before and the wind velocity read three hours earlier. The latter formula requires a knowledge of predicted astronomical tides in the form of heights listed at hourly intervals, rather than as a table of predicted times and heights of high and low water. With present day computing facilities, it is actually easier to compute hourly tide heights than it is to compute the highs and lows. It is clear that using wind data predicted several hours ahead, an estimate of the height of the storm surge can be projected even further forward into the future.

By this means, at 2 p.m. on June 28 last year, the writer predicted that the river level at Inner Harbor would reach a highest level equal to the previous extreme value of 13.2 ft., at approximately 6 p.m. With this information, the Regional Director of the Bureau of Meteorology broadcast warnings of the excessively high tides expected. As referred to previously, the average wind speed fell around 5 p.m. and a high water of 13 ft. was recorded at 5.12 p.m. The prediction in the tide tables (Ref. 2) was for a high water of 9.2 ft.

There are a number of uses for a formula which predicts storm surge heights from air pressure and wind velocity readings. Sea levels which include meteorological effects, can be given several hours in advance by adding the predicted storm surge height to the predicted astronomical tide height. The results can be used to warn people living in low-lying sections of the metropolitan area of the possible danger of flooding; to warn appropriate authorities controlling storm water drains to close valves to

prevent roads being flooded by sea or river water backing up the drains, and to warn small boat owners so they can adjust their moorings. The formula can also be used to predict possible extreme storm surges from estimates of worst weather conditions; when added to the highest possible predicted astronomical tide the figure obtained indicates a possible maximum sea level to be expected. This has direct application for coastal engineers concerned with the building of coastal structures such as sea-walls and levees.

In addition to this research into storm surges, work concerning the beach erosion on the Adelaide foreshore has been underway in the Department of Civil Engineering of The University of Adelaide since the late 1960's. Recently, R. Culver completed a five year study of this problem (see Ref. 5). One of his main proposals is for the stockpiling of sand at key locations along the metropolitan sea front so that it will spread along the beaches and return them to their original, natural state. Only then will the storm damage caused by a combination of excessively high tides, big waves and strong winds be minimised. With the success of this plan will come the saving of several millions of dollars of public money every decade, money normally spent on repairing sea-walls, beach facilities and esplanades which are damaged because of the lack of protective sandy beaches.

ACKNOWLEDGEMENTS.

The author thanks the Advertiser and the News for permission to reprint sections of their reports on storm damage, and the S.A. Regional Bureau of Meteorology and the S.A. Department of Marine and Harbors for supplying relevant data for the research being carried out, in the Department of Applied Mathematics at The University of Adelaide, on the problems of air-sea interaction.

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INSECTS AND WEATHER

by

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No other animals except man have so persistently and successfully colonised the earth as have the insects. Snow and ice are not impossible barriers to them, neither are hot springs, salt lakes or deserts, all of which have their quota of insect life. Soil and fresh water have their own great populations of insects and the sea is the only medium that has proved a barrier to them. Even so, there are some insects that live at the seashore below high tide level, and are submerged twice daily.

Man, in colonising the earth, has modified the environment to suit him, growing his own food and providing shelter from the weather. But the success of insects has been due to their ability to adapt to available food and to climate. The most unpromising substances, despised by other animals, constitute the foods of one or more species of insects - foods such as peppermint, ginger, liquorice, wine bottle corks, paint brushes and museum specimens. Some insects live on exotic diets like opium, cayenne pepper and cigars but the most enterprising insect however must be the small fly that spends its immature stages in pools of petroleum round the oil wells in Southern California, and is not known to live anywhere else.

But no matter what its food preferences may be, or what environment it lives in, no terrestrial insect can escape the effects of meteorological factors - temperature, humidity, wind, light, solar radiation and barometric pressure. You might perhaps imagine that meteorological conditions can affect only those animals that are exposed to the direct action of the atmosphere. However, conditions in the soil, inside a tree trunk or in a bag of grain are affected by one or more of the major meteorological factors. In any case, most insects at some stage of their lives, usually as adults, spend a shorter or longer time exposed to all the conditions of the atmosphere.

The social insects - ants, bees, wasps and termites - have anticipated man in developing methods of maintaining their communal nests at a relatively even temperature and humidity, but even then adults must emerge to mate, to found new colonies or to seek food for the colony. Climate is an ever present factor in all stages of the lives of insects.

In discussing the prevalence of insects, it is advisable to make a distinction between climate and weather, and the ways in which they influence insect populations. Every species of insect has the natural tendency to spread as widely as possible, but this tendency is checked by certain factors which make it impossible for every species of insect to live everywhere. In fact, most species of insects are confined to fairly clearly defined regions. Geographic factors such as mountain ranges, large deserts and oceans provide natural barriers to the spread of insects. But climate is the major factor that determines their distribution, for no insect species can maintain itself in any area where it can not reproduce at an adequate level every year. Climatic factors such as regimes of temperature and humidity, rainfall and daylength are important, for they affect insects directly and indirectly through their effects on food supplies.

Climate then sets the broad limits of the distribution of any insect species. Within this climatic area - the habitat of the species - the abundance of the insects will vary, for conditions can never be equally favourable throughout the whole of the habitat, and in some areas the species may only occur infrequently.

The abundance of the species within its habitat is influenced by weather - that is, by local variations from day to day or from year to year in the main meteorological phenomena. In some cases conditions in parts of the habitat may be favourable every year, but in others, particularly those on the fringes of the habitat, the insects may appear very occasionally. Thus, since weather is variable, we find great variations in the numbers of many insects.

Temperature is a dominant factor since insects, unlike higher animals, have no mechanism for controlling the temperature of their bodies. However, insects appeared on the earth before man, and with millions of years to adapt, they have developed physiological and behavioural adaptations that enable them to survive in habitats in which temperatures at various times of the year may be outside the range they can normally tolerate.

Thermotactic responses cause many insects to move away from sources of heat and cold. Thus in arid areas they seek shelter from the sun during the day, and in cooler areas will seek exposure to the sun. Other insects, through physiological adaptations, are able to enter a stage of arrested development so that they can survive extremes of temperature. For example, insects in cold climates are able to withstand temperatures well below freezing point through physiological adaptations that allow them to survive even though their bodies may be frozen solid.

Temperature also affects the rates of reproduction, growth and development of insects. For example, the common housefly breeding in a heap of fermenting compost in hot weather may pass through all stages from egg to adult in only six days, but at 60°F may require forty days to pass through its life cycle.

This means that insects that have more than one generation per year may produce more generations and more individuals per generation in hot weather than in cold weather. Where the life cycle may be shortened, as in the case of the housefly to only six days, a fourteen-day heatwave may result in the production of at least one extra generation.

Humidity and precipitation are also important. Rainfall has a number of direct and indirect effects. Indirectly, it affects the growth of plants, and so the food supplies of insects, and it determines in most instances the levels of soil moisture. Many insects spend some part of their life cycle in the soil, and both excessively high and very low soil moisture levels influence the survival of these stages. Australian insects in general are

adapted to dry conditions, and so suffer severe mortalities in wet seasons for high humidity favours the development of fungal, bacterial and viral diseases of insects which can often cause virtual destruction of a whole population.

Rainfall directly affects many insects, particularly tiny insects such as thrips and parasitic wasps. Small insects are easily trapped in droplets of water and may drown before the droplet evaporates. Heavy rains wash small insects off their food plants and quite large populations may disappear after heavy rains.

Wind plays a major part in the dispersal of many insects and we are only now beginning to find just how significant this is in the dispersal of insects in Australia. Microwave radar now being used to track flights of grasshoppers has shown that major flights of insects occur very frequently, and occasionally the numbers in the air at dusk have been so great as to cause a white-out of the screen.

The abundance of insects is thus directly related to weather conditions in a variety of ways. Many insects have tremendous powers of reproduction, which enable them to take advantage of even brief periods of suitable weather. Fortunately, a very high proportion of insects die an unnatural death. They may be devoured by natural enemies or fall victim to disease, or may be unable to mate or may die from accident or cannibalism. But enough always remain for the species to survive.

The ability of insects to reproduce under suitable conditions is shown by the following calculations of the rate of increase of the housefly. In Europe this insect has an average 7 generations per year, and each female lays an average of 120 eggs. If all their progeny survived, by the end of the summer a single pair of these flies would have no less than 5,598,720,000,000 descendants. In hot countries like Australia, where the housefly might pass through 14 generations a year, a pair of Australian

houseflies would at the end of the breeding season boast of 15.67 quadrillion progeny, which would weigh 219 billion tons! Fortunately for the world and its other inhabitants, over 95% of housefly progeny die unnatural deaths !

The complexity of the effects of weather conditions on insects is a major problem in both basic and practical entomology. It is, for example, not simply sufficient to study the effects of temperature or the effects of humidity on their own. We have to relate the two, using for preference saturation deficiency as a measure of the evaporating power of the air. We have to relate these to the stage of the insect, the time of the year and the degree to which the insect has had time to acclimatise.

The aim of applied entomology is that we should be able to forecast outbreak years, so that farmers may be warned, but the amount of information required will in most cases prevent this for a long time.

Now I want to discuss some examples of the way in which Australian insects are influenced by weather conditions. The Australian bushfly is an example of an insect whose abundance is directly related to temperature and rainfall, and whose distribution is influenced by winds. Although the bushfly has always been a problem in Australia, little research was done until C.S.I.R.O. initiated a full study of its ecology in 1967. As a result of this study, possibilities of some control of this pest are now emerging.

There are two main patterns of fly abundance. In the inland tropics the flies appear after the summer rains and increase to a peak in the autumn. Their numbers decline in winter, and they are rare in late spring and may be missing during the period of heavy summer rains. They reappear in late summer. In southern areas the flies are absent in winter but reappear in spring, reaching peak populations in late spring and early summer. Numbers decline markedly during summer, but in some years there is a recovery in autumn, followed by a rapid decline in late autumn and their disappearance in early winter.

These periods of abundance are related firstly to warm conditions. The

flies tend to be inactive at temperatures below 10°C, but with rising temperatures their activity increases, the number of eggs laid rises, and the life cycle is shortened. Thus total fly numbers increase as temperatures rise.

Periods of abundance are also related to rainfall in so far as this influences the quality of the food for the larvae. Although rainfall will have some effect on the quantity of food, its most important effects are on the quality of the food. The larvae of the bushfly feed on the dung of animals, and the quality of the dung as food for the larvae is related to seasonal growth of pastures. Dung of animals feeding on young green grass is a different quality of food for fly larvae from the dung of animals feeding on dry grass.

In the tropics, pasture growth follows the heavy summer rains, and thus the main breeding season of the flies begins after the summer rains and peak numbers occur in autumn. Then as pastures mature and dry out in winter, food quality becomes a limiting factor, and numbers decline during winter and spring.

In the south, the main period of pasture growth begins in spring after the winter rains. Once temperatures rise sufficiently, the flies begin to breed, and peak numbers occur in late spring and early summer. Then as pastures dry out, food quality becomes limiting, and numbers decline. If the season breaks early, while temperatures are still above 10°C, a further breeding cycle will occur.

The great importance of the quantity and quality of food may be seen in areas where cattle are grazing irrigated pastures, for in such areas fly numbers continue high throughout the summer. Research has shown that bushflies do not survive the winters in southern Australia. The last autumn flies are in effect a "lost generation", in that they leave no progeny to recolonise the region in the following year. In warmer regions, where food quality is

maintained by autumn rains, fly breeding continues throughout the winter. Somewhere near the Queensland border, the July climate becomes marginal for bushfly survival, and no breeding occurs in winter south of this level. Yet adult flies appear throughout the year in the marginal area.

The question then is, where do flies come from to infest southern Australia every summer? The answer is "Blowing on the Wind!" In winter, the weather of the central latitudes is characterised by recurring warm north-north-west winds associated with anti-cyclones. These winds regularly displace flies southward, until they reach temperature limits for flight. These flies do not breed, but are also a "lost generation".

In spring, the warm north-north-west winds penetrate further south, carrying flies down to new temperature limits. Increasing temperatures after winter bring pastures to maturity successively further southwards, so that the region most favourable to bush fly reproduction is extended southwards again each spring.

You can readily observe this influx of flies each spring if you remember to watch for the occurrence of northerly winds, for after such winds have prevailed for a day or so there is usually a noticeable increase in the fly population. This population will stabilise until the next wave of younger and more active flies is swept through.

The distances which the flies may be passively borne on winds are quite impressive. The Meteorological Bureau estimated the trajectory of a passive wind-borne fly on September 12th, 1968. They estimated that if the fly left Nyngan - a little over 100 miles north-north-west of Parkes - at 9.00am., it would reach the limits of distribution round Yass by 5.30pm. on the same day, a flight of some 300 miles.

With the identification of the breeding areas of the fly, the possibilities of control are improved, for if fly populations north of Bourke

can be reduced, the numbers of flies reaching the south each year will also be reduced. Control measures being attempted include the introduction of dung beetles. These insects work very fast in taking animal dung down into the soil to provide food for their larvae and thus reduce the food supply of fly maggots. Introductions to N.E. Queensland have already been somewhat successful in controlling buffalo fly in that area. However, climate and weather figure strongly in plans for further introductions. The beetles introduced to coastal Queensland are not adapted to the climatic conditions of the main bushfly breeding area, and a search is now being made in other countries with appropriate climates, for more suitable species.

A more simple and direct effect of rainfall can be seen in our own gardens. Aphids, which are an annual problem on roses and citrus trees, thrive best in low temperatures. At high temperatures their reproductive rate is reduced while at the same time parasites and predators - particularly ladybirds - become very active. Aphids are clumsy, slow moving beasts, and are easily washed off the plants by heavy rain, while high humidity and high temperatures encourage the development of fungi which attack and destroy the aphids.

A recommended control for home gardens is the simulation of heavy rain to wash the aphids off the plants. Most of them are unable to return to the softer terminal shoots on which they normally feed. A strong jet of water from the hose once a week is usually quite adequate. It is most effective to do this in late afternoon on a warm day, since at that time the aphids have unplugged their mouthparts from the plant and are more easily removed.

The green caterpillars of the moth Heliothis are serious pests of agriculture, and also do damage in your garden, where they bore into the buds of carnations and roses, and into sweetcorn cobs and tomatoes. Over the years that we have been studying this insect at the Waite Institute, we have seen how it is affected by the weather in several ways. In the mid-north of the state it appears on pea crops in October, but spraying was usually ineffective

once the caterpillars were hidden in the pods. However, our studies showed that the eggs were laid on the flowers of various weeds, and that there was a mass migration of caterpillars to the peas, usually on a day of high humidity and relatively high temperatures. Spraying of the crops at this time produced a high degree of control, with much lower doses of insecticide. We have not as yet gained enough information to gauge the effects of delayed migration through prolonged cold weather, but it is probable that this would result in death by starvation of many caterpillars.

In lucerne crops in summer, light showers, or at times a heavy dew following a hot day, may lead to the outbreak of a viral disease which can virtually eradicate a population of Heliothis overnight. Use of this knowledge does at times enable farmers to avoid spraying until they see what effects such weather conditions may have had.

One major problem with Heliothis is that although it is an extremely serious pest, there is little chance of non-insecticidal control being possible in the very near future, and insecticides, particularly DDT, will be used to control it for many years to come.

Recently we have seen another possible effect of weather conditions on the populations of Heliothis in South Australia. Although it suddenly appears in the mid-north in October in large numbers, and in the upper south-east makes its first appearance at the beginning of December, we do not find over-wintering larvae or pupae in these areas. This suggests that it cannot over-winter in South Australia.

Late last year we gathered all the data we had obtained from light trap catches, and extracted the occasions on which peak flights had occurred. The Bureau of Meteorology made an analysis of weather data immediately preceding these periods, and found a strong correlation between periods of two to three days of strong northerly winds and the peak catches of Heliothis. This was

support for the theories that we had been developing, that Heliothis migrates in from somewhere to the north or northeast every year - we suspect from north-west New South Wales or south-west Queensland. Further than this, although the moths and larvae are abundant in the lower and mid-north in spring, they are very rare in summer, and again we postulate that the moths that appear in the upper southeast are the second generation, which have migrated down from the mid-north. There was considerable support for this theory in the past summer, when we had few northerly winds, and Heliothis did not in fact appear in numbers until late January. We hope to make further light trap studies in the future, and with the help of the Bureau, to find out where these moths originate.

Another important agricultural pest which is strongly influenced by weather conditions - particularly rainfall - is the pasture cockchafer Aphodius, which is a problem in the lower southeast, and in the Adelaide hills. These small beetles fly in swarms in January - March after rain, and in fact are sometimes called rain-beetles. Rainfall affects their abundance at different times of the year. Low rainfall in January - March reduces the survival rate of the females and the eggs.

Eggs hatch after absorbing moisture from the soil, but the larvae remain near the eggs without feeding much until rain wets the soil. Thus the weather between March and May is critical for survival of the grubs, and if this period is dry, most of the larvae will die. If they survive this period, they may be affected by rainfall from June to September. If rainfall is excessive, so that the soil is very wet for prolonged periods, the larvae die, particularly from the effects of invasion by Cordyceps, a fungus that multiplies in wet soil.

An interesting sidelight on the effects of temperature on insects is that the rate of chirping of crickets increases with temperature. In cold weather they chirp slowly and the noise is more of a rattle; in warm weather they chirp very fast and produce a high-pitched sound. Some ingenious

scientists have in fact produced a formula by which it is possible to calculate temperatures from the rate of chirping of crickets. This applies to the English cricket, and is not necessarily applicable here:

$$T\ (^{\circ}F) = \frac{5 + \text{Number of chirps per minute} - 40}{4}$$

The spread and effectiveness of myxomatosis of rabbits is also directly related to weather conditions. Myxomatosis is spread by mosquitoes, but when the disease was first introduced, there was little spread from the first release sites for almost two years. Then there was a virtually explosive spread over a wide area. This was due to above average rainfall which enabled mosquitoes to breed abundantly and spread widely, carrying the disease with them.

Plagues of grasshoppers and locusts also arise from certain effects of changing weather conditions. The story is long and complicated, but in broad outline is as follows:

There are only a few areas in which plague locusts and grasshoppers can breed continuously. These are outbreak areas, and the Australian plague locust exists in four such areas, all in New South Wales. When a period of suitable conditions - particularly above average rainfall and temperatures occurs - the food supply increases and the locusts multiply and spread further away from the main outbreak areas. As conditions return to normal, much of this food supply dies off, forcing the locusts to move to the remaining areas of food. As this continues and the insects crowd together, they undergo a change in their behaviour. From being virtually solitary insects, they become gregarious, remaining together in large bands. Eventually, as they develop wings, these huge bands take off and fly in swarms, always maintaining their coherence. When the swarms alight and locate suitable egg-laying sites, the females produce their eggs and eventually die. If there is sufficient rain to keep the soil wet, these eggs will hatch to produce another generation which will migrate further. This step by step movement will continue until the locusts reach an area where eggs cannot hatch, or

nymphs survive, and the invasion ends. The current grasshopper plague in the north of South Australia has been moving down from the north for two years now. It is interesting to note too that there were serious outbreaks in South Australia from 1933 to 1935, and these were related to the four preceding years which were the longest series of floods on Coopers Creek for twenty years.

In summer, from time to time, brown termites - white ants - fly at night, coming into houses in large numbers and leaving their wings on the floor by windows or lights. These are males and females of the grass roots termite - Hamitermes neo-germanus. Termites disperse by producing winged males and females which leave the nest and found new colonies. Hamitermes usually swarms in the evenings of hot days, and at times when the barometric pressure is falling. Response to falling barometric pressure in soft-bodied insects such as termites is logical behaviour, since high humidities and possibly rain are more likely to occur with falling barometric pressure. These insects cannot withstand dry conditions and survive in low rainfall areas only because they construct their nests in such a way as to retain a high humidity, but the period of founding a new colony is critical.

There is still a great deal to be learned about insects and weather, and it is when we have a year such as the one we have just had, that one becomes frustrated at our lack of knowledge, but also encouraged somewhat at the possibilities of forecasting insect outbreaks.

Take for example, the problems of insects in lucerne seed crops this this past year. In October - November, pink cutworm caterpillars caused severe damage in older lucerne stands. Usually the damage is most serious in newly sewn lucerne, and old stands are rarely affected. The reason for this damage, we suspect, was the lack of rain in October, which allowed for a high survival of young larvae.

Heliothis, as was mentioned earlier, did not appear in numbers in December as expected, but there was severe damage by a species of grasshopper

that is always present, but is rarely seen in significant numbers. Reasons for this were possibly rain in November - December.

The lucerne podborer Etiella was at its highest population since 1957, and possibly since 1954. Reasons are unknown, but it was an effect of the weather in some way. Lucerne leaf-roller, rarely noticed in South Australia, became quite serious in some areas, the reason probably being damp weather.

Blowfly strike of sheep was also severe in South Australia in spring and summer, again due to rainfall and prolonged high humidities, which meant that sheep did not dry out and thus were continuously attractive to ovipositing female blowflies.

The challenge for the future is for entomologists and meteorologists to work together to gain a better understanding of weather and insects, so that we can take more advantage of the effects of weather on insect populations, and thus further our aims of reducing the use of insecticides, without any major increase in the damage done by insects.

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